The Relationship between Lean Meat Yield and Birth Weight in New Zealand Romney Sheep

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A Dissertation submitted in partial fulfilment of the requirements for the

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Abstract

Over recent years sheep numbers in New Zealand have steadily declined due to increased expansion of dairying. This has caused not only reduced ewe breeding flock numbers but also pushed lamb production to less productive areas. New Zealand lamb exports were worth $3 billion in 2016 (MIA, 2016) therefore a significant contributor to the red meat industry which is the second highest export earner behind dairy products. Another challenge to the industry is to meet expectations of the consumer who want leaner carcasses with less fat. Lean meat makes up 50-60% of total carcass weight, therefore selecting for increases in lean muscle is of benefit to increase carcass value and financial return. Birth weight has been observed to influence lean meat production through muscle mass and growth rates, but little is known about its effect on lamb final weight and carcass traits such as lean meat production. Could emphasising the importance of ewe nutrition be of financial gain to farmers if resulting lambs have production benefits over and above improved survival rates due to increased lamb birth weights.

2521 NZ Romney ram lambs from 2009-2016 were investigated for an association between birth weight and subsequent weaning weight and final weight with carcass traits (lean meat,

leg, loin and shoulder yield). SPSS v24.0 was used for calculating correlations between birth weight, weaning weight and final lamb weight with carcass yield traits and between subject effects (sire, birth weight, weaning weight and final lamb weight). Excel 2013 was used for basic statistical analysis (means and standard deviations).

Birth weight was found to have a positive correlation with weaning weight and final lamb weight (0.467 and 0.152 respectively) and this was highly significant ($p<0.001$). Furthermore birth weight also greatly influenced lamb growth rates with the heavier the birth weight, the greater the growth rate. Low birth weight (2.75 kg) grew at 81.25 g/day, medium birth weight (5.88 kg) at 241.28 g/day and high birth weight (9.50 kg) at 366.66 g/day respectively. Birth weight also was correlated positively with leg, loin, shoulder and total yield (lean meat) with 0.018, 0.055, 0.147 and 0.078 respectively. Only shoulder and total yield were significant ($p<0.001$). Weaning weight was found to be positively correlated with final lamb weight (0.413) and this was highly significant ($p<0.001$) it was also correlated positively with carcass yield traits (loin, shoulder, total yield) which were highly significant ($p<0.001$) however leg yield was found not to have a significant correlated ($p> 0.005$). Final lamb weight was positively correlated with loin, shoulder and total yield (0.189, 0.151 and 0.055 respectively) and these were all highly significant ($p<0.001$). Leg yield was found to have a negative correlation (-0.120) and this was also highly significant ($p<0.001$). Birth weight was found to be significantly affected by sire ($p<0.001$), while lean meat was significantly affected by both sire and weaning weight ($p<0.001$), leg yield was sire and final lamb weight ($p<0.001$), shoulder yield year was sire and lamb final weight ($p<0.001$) and finally loin yield, sire, weaning and final lamb weight ($p<0.001$).

These results suggest that birth weight is important for maximising yield as it influences growth rates of lambs and is strongly correlated with lamb weaning weight. Weaning weight is strongly correlated with lamb final weight which had the greatest influence on carcass yield traits, as expected due to a strong genetic correlation with live weight and carcass weight. Overall these results reemphasise the importance of maximising lamb birth weight and reducing the factors which influence it negatively such as inadequate ewe nutrition in order to have lambs which have high yielding carcasses.

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"Success consists of going from failure to failure without the loss of enthusiasm. Success is not final, failure is not fatal: it is the courage to continue that counts" – Winston Churchill

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Chapter 1 Introduction

In lamb production systems for meat production increasing productivity is achieved through selecting for increased fecundity (increased ovulation rate hence increasing resulting litter size), increased growth rates, muscling (lean meat production). This allows resulting lambs to reach optimum market weights faster with premium meat yield (high proportion of high value cuts) (Dwer & Bunger., 2012). For New Zealand lamb production systems selection is based on rapid growth rates and high meat yield to obtain early season market premiums in order to free up land on farm for finishing more lambs or for other stock classes. By selecting for lambs which grow faster and are off farm earlier this can help reduce labour inputs and animal health costs (Golding et al., 2008; Judson et al., 2009).

The three growth traits which have an important role in lamb meat production are birth weight, pre and post weaning weight. Therefore breeding for optimal birth weight and increased weight gain allow for increased productivity. Birth weight is related to lamb survival with lambs being born between 3.5-5.5 kg having the greatest rate of survival (Dalton et al., 1980) and outside of the range being below 3 and above 6.5 kg having low changes of survival due to reduced cold tolerance and increased rate of dystocia (Dalton et al., 1980). Litter size also has an effect on birth weight and optimum survival of multiple born lambs is between 1-3.5 kg (Hinch et al., 1985). Birth weight therefore is not just important for driving economic productivity of the farm, but also in reducing losses of lambs during lambing and increasing lamb survival.

Lean meat production is influenced by muscle fibres which the number is determined prior to birth during the embryonic and foetal development period in which the development of muscle is characterised by an increase in muscle fibre number due to myoblast hyperplasia. Muscle growth after birth (increase in muscle size but not fibre number) results from cellular hypertrophy which is characterised by an increase in DNA and protein content (Kang et al., 1985). Hence an individual’s potential for lean meat production largely depends on both the number of pre-natal formed fibres and the post-natal rate of muscle fibre hypertrophy (Larzul et al., 1997).

Birth weight is influenced by nutrition of the ewe, any nutritional deficiency during early to mid-gestation not only reduces muscle fibre number but also the muscle mass (Du et al., 2009). A reduction in muscle mass causes a reduction in lamb birth weight which can affect not only lamb survival but the potential growth of that individual. The focus of this dissertation is on lamb birth weight and if it could be considered a predictor for carcass yield such as lean meat production and if so, could reemphasise the importance of ewe nutrition to be able to have lambs which reach maximum potential for carcass yield in order to increase financial return to New Zealand (export) and to the individual farmer.

Chapter 2

Literature review

2.1 New Zealand lamb and red meat sector

Red meat is an important export earner for New Zealand (NZ) and was worth $7.5 billion in the year ending in June 2016. This was a $200 million increase compared to the previous year (MIA, 2016). With red meat exports being the second greatest export earner after dairy exports, emphasis on increasing export volume and providing consumers with what they want, is crucial to improving export earnings. Furthermore, having sufficient flexibility to deal with changing markets (resilience) is also important as market demands are ever changing.

In NZ many abattoirs base their payments to farmers for lambs on a grading system that incorporates carcass weight and fat depth (MIA, 2011). However a challenge for the NZ sheep industry is to meet abattoir quality expectations, and in 2007 less than half of NZ lamb carcasses met these expectations (Gooch, 2007). Accordingly, the long term challenge for the industry in the context of declining sheep numbers, is to get improvement in the number of carcasses that meet export market expectations and standards.

Sheep meat exports were worth $3 billion in 2016 (MIA, 2016. Export volumes have increased to all major markets including China (12%), United Kingdom (7%) and the United States (14%) (MIA, 2016). There was also an increase in the volume of exported high-value chilled cuts, these increasing by 9% (71,322 Tonnes) by weight and 12% in value ($863 million) according to the annual MIA, 2016 review.

Figure 1 summarises the biggest importers of New Zealand sheep meat, with China being the largest market that New Zealand exports to (21%) and the United Kingdom being slightly behind with 19% respectively. Other markets are Switzerland, Malaysia, and Mexico, suggesting there may be new opportunities to increase sheep meat exports to other countries in the future.

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Figure 1: Top 10 sheep meat markets of value for NZ exports from the year ended June 2016 (From MIA, 2016).

Another important aspect of the red meat industry, are the co-products produced along with the meat. These are valuable and recently were worth $1.37 billion (MIA, 2016). They account for 18% of total industry exports. Figure 2 illustrates the different types of co-products that New Zealand exports and what percentage of value these account for. Hides and skins (33%) are the most valuable co-products, followed by casings, runners and tripe (19%) and edible offal (17%) (MIA, 2016).

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Figure 2: Co products of the NZ meat industry and their relative percentage of value (Adapted from MIA, 2016)

NZ exports 92% of what it produces in sheep meat to over 120 countries throughout the world (MIA, 2016). The business model of the red meat sector is concerned with finding markets for all the different parts of the carcass including co-products, the ambition being to minimise industry wastage. To assist achieve this, sheep breeding programs need to be focused on producing lambs that are fit for market expectations, although these expectations do differ depending on the country being exported to. Market demands can also change when for example new understandings about particular products become known to customers. For example, fat is now recognised as being crucial for healthy brain development and it has been extensity researched and confirmed that fat is not only good for human consumption, but can also increase the eating experience with meat. This stated, some countries for instance some of the European states, prefer lean meat with little to no fat. Therefore depending on the export market, lamb breeding programs also need to be adaptable to cope with change and new trends in markets.

2.2 Skeletal muscle development

Understanding of skeletal muscle development is crucial for producing animals that are useful to meat production and that have greater genetic potential for breeding. Skeletal muscle represents a large proportion of the total carcass of an animal, and in sheep it accounts for 50-60% of carcass weight (McCourd, 1998). Skeletal muscle growth is therefore critically important for meat production systems.

Additionally a reduction in body size would imply that development and or growth has been in some way impaired resulting in a consequential decrease in the overall muscle mass of the individual. Due to the process of the development of skeletal muscle mass, the maximum amount of muscle fibres is determined prior to birth, so consequently can be affected by environmental factors which could be affecting maternal reserves and or foetal development. For example genetically the individual might have a certain number of muscle fibres, however if adverse prenatal conditions such as maternal undernutrition and denervation (McLennan, 1983) may reduce the number of muscle fibres which can impose permanent effects on postnatal growth rate (Hegarty and Allen, 1978) and size (Bedi et al., 1982). Therefore in order for an animal to reach maximum production potential all factors must be taken into account (genetic + environment).

2.2.1 Skeletal muscle and birthweight effects

A comparison of lambs with low and high birthweights (Hunt et al., 1996) revealed that although muscle weight was reduced in lighter birthweight lambs, fibre number was not affected. Also unaffected was muscle fibre phenotype (fast or slow twitch), but the DNA content of the muscles from lambs with heavier birthweights was greater than low birthweight lambs, suggesting that heavier lambs have higher muscle nuclei numbers (Hunt et al.,1996). Litter size also has an effect on muscle size. Twinning, which is associated with lower birthweights, leads to lambs having proportionally smaller muscles at birth (Sailer et al., 1994) and they tend to grow more slowly than singles postnatally. This can result in lambs that are twins reaching market weight up to 3 weeks later (Nordby et al., 1987). These observations could suggest that body size at birth may be an indicator of alterations in muscle development and growth during foetal life (McCourd., 1998).

Knowledge of foetal development is crucial in order to maximise the growth potential of the livestock (Du et al, 2009). Development of muscle can be influenced by nutrition (environment) and by genetics. Studies of malnutrition and over nutrition during the gestation period have been shown to affect livestock growth performance (Bispham et al, 2003; Ford et al, 2007). Genetic influences re the “other half” of the equation of skeletal muscle development.The foetal stage has been shown to be crucial for the development of skeletal muscle, as post-birth there is no net increase in muscle fibre number (Zhu et al., 2004). Instead the size of the fibres increase as the animal matures. However, if animals have been “held back” nutritionally in-utero a decrease in muscle fibres could occur due to foetal programming and permanently reduce the muscle mass. This would affect animal performance (Du et al., 2009).

Three cell types produce the basic structure of skeletal muscle (myocytes, adipocytes and fibroblasts). The majority of these three cells are in foetal muscle are derived from the same pool of mesenchymal stem cells. Therefore understanding the mechanisms involved in mesenchymal stem cell differentiation (within foetal muscle) are pivotal to understanding meat production efficiency (Du et al., 2009).

2.2.2 The development of skeletal muscle in-utero (foetal programming)

The development of skeletal muscle is initiated during the embryonic stage (Cossu & Borello., 1999). All muscle cells originate from the myotome and dermomyotome regions of the somite (Maltin et al., 2001). Mesodermal precursor cells need to enter the myogenic lineage, however this requires the up-regulation of basic helix-loop-helix (bHLH) proteins, as well as the transcriptional activators MyoD and Myf5)

(Cossu & Biressi., 2005). The precursor cells are able to differentiate and proliferate to establish a pool of myoblasts. Myogenin (MYOG) and muscle regulatory 4 (MRF4) assist in differentiation of the myoblasts (Molkentin & Olsen., 1996; Olsen.,1992; Han., 2014). Differentiated myocytes come about by withdrawal at the first phase of the cell cycle (G1), known as the gap phase. They then begin to express specific muscle cell proteins. Muscle fibre creation occurs through mono-nucleated myocytes fusing to become multinucleated myotubes (Askkura et al., 2002, Han.,2014) and subsequently post-natal muscle growth is mainly due to an increase in muscle fibre size, without the formation of new muscle fibres (Du et al., 2009). Primary myofibres that are formed during the initial stages of the fusion of myoblasts provide a framework for the development of a larger population of smaller secondary myofibres (Han., 2014). This is made possible through a second wave of differentiation of foetal myoblasts. In the final phase, the determination of muscle fibre number occurs. The terminal differentiation allows myotubes and myofibres to be fused into primary and secondary muscle cells (Schiaffino & Reggiani.,1996).

Muscle satellite cells are myoblasts that do not differentiate at first and that do not form fibres. These cells are able to divide and serve as a source of new myonuclei by contributing to fibre growth during post-natal growth. They participate in muscle regeneration as well as muscle repair processes (Heslop et al., 2001; Schultz., 1996).

2.2.3 Skeletal muscle development in late pregnancy (day 12-34 of development in utero) to birth

Various signals are involved in order to initiate the development of skeletal muscle. Mesenchymal stem cells commit to myogenic lineage as a result of receiving signals from neighbouring tissues (Kollias & McDermott., 2008). These signals include Wingless and Int (Wnt) and sonic hedgehog, which regulates the expression of paired box (Pax) 3, 7 and Glioma-associated oncogene homolog 1 (Gli) (Kassar-Duchossoy et al., 2005; Du et al., 2009). This initiates expression of myogenic regulatory factors (MRF) (Du et al., 2009). During the embryonic stage (discussed above), a portion of cells in the mesoderm first express the MRF myogenic factor -5

(Myf5) and myogenic differentiation 1 (MyoD) (Buckingham., 2001). As previously discussed the myoblasts undergo differentiation. Additionally myogenin is also initiated by myoblasts and is an important MRF. Myogenin is crucial for the formation of multinucleated myotubes (Du et al., 2009). Myogenesis is regulated by various MRF in order to form a mature muscle fibre (Kollias & McDermott., 2008) (figure 3).

After differentiation has occurred, myoblasts migrate into adjacent embryonic connective tissue and other muscle-specific genes are expressed including myogenin (MYOG) and myogenic factor 6 (MYF6) (Knudsen et al., 1990). Proliferation is continued until a shortage of Fibroblast Growth Factor (FGF) has been reached. Development at this stage in different regions of the embryo precursor allow cells to be differentiated into different muscle types (Skeletal, cardiac and smooth) (McKensey et al., 2001). Multinucleated early myotubes are formed once myoblasts are fused into muscle "straps" after proliferation (Yagami-Hiromasa et al., 1995). Muscle cells have to mature, and in response to myostatin signalling the up-regulation of cyclin-dependant kinase inhibitor 1A (Cip 1, p21) occurs as illustrated in figure 3.This causes an inhibition of cyclin-E- Cdk2 and retinoblastoma (Rb) protein activity, leading to the arrest of myoblasts in the G1 cell cycle phase, which leads to inhibition of their proliferation (Thomas et al., 2000). Satellite cells are also proliferated (McCroskery et al., 2003) and this can result in development of new fibres (Charge & Rudnicki., 2004).

Myostatin (MSTN or growth differentiation factor 8) inhibits the differentiation of myoblasts into mature muscle fibres (Carnac et al, 2006). It achieves this by binding to activin type II receptor (Joulia-Ekaza & Cabello, 2007) and utilises Activin-like-kinase Receptor-4 (ALK4) in myoblasts (Lee et al, 2015). These factors are then able to induce myostatin-specific gene regulation (Han., 2014). Myostatin is responsible for the regulation of myoblast number, myofibre number and subsequent muscle differentiation (Thomas et al., 2000). On a cellular level the loss and or malfunction of myostatin down-regulates p21 and decreases cytoplasmic phosphorylation of Smad2/3 (Ohsawa et al., 2008). This has a knock-down effect causing hyper-phosphorylation of the Rb protein and it's binding to the E2F-DP transcription factor (Otto & Patel., 2010), consequently causing progression of the cell cycle into the S-phase of normally quiescent satellite cells. These proliferate and fuse with existing muscle fibres, leading to an increase in muscle fibre size

(McCroskery et al., 2003; Tobin & Celeste., 2005) known phenotypically as double muscling. Double-muscling has been well documented in cattle, mice and more recently sheep. This phenotype is caused by a decrease in myostatin levels leading to muscle cell hyperplasia or muscle cell fibre number increase, and hypertrophy (an increase in muscle cell size). This leads to an increase in skeletal muscle mass (Thomas et al., 2000).

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Figure 3. The process of myogenesis (Hettmer & Wagers, 2010).

2.2.4 Postnatal skeletal muscle growth and development (birth- slaughter)

During the embryonic and foetal development periods, the development of muscle is characterized by an increase in muscle fibre number due to myoblast hyperplasia. Muscle growth after birth (postnatally) results from cellular hypertrophy, which is characterized by an increase in DNA and protein content (Kang et al., 1985) without an increase in muscle fibre number (Smith, 1963). Muscle hypertrophy can occur throughout all stages of growth and requires proliferation of satellite cells in late foetal and postnatal life (McCourd., 1998).

The most efficient animals for meat production are those which gain weight and reach a mature body size rapidly and with minimal fat deposition during the post-natal muscle growth period (Han., 2014). They are accordingly more efficient at converting feed energy to lean meat. If selection for larger mature body size or rapid lean tissue growth occurs, this can lead to increased body weight.

An individual's potential for lean tissue growth largely depends on both the number of pre-natally formed muscle fibres and the post-natal rate of muscle fibre hypertrophy (Larzul et al., 1997). It is likely that the accumulation of myonuclei by the foetus is the most important development factor for the regulation of the post-natal growth potential of ovine muscle (Greenwood et al, 2000) which will be discussed further on in relevance to foetal nutrition.

2.2.5 Genes that affect the development of skeletal muscle

Presently nine distinct loci have been identified that influence carcass composition in sheep (Cockett et al, 2004) Table (1). This includes the three well known muscle phenotypes described in sheep: Callipyge, Carwell and double-muscling.

Table 1: Genes and QTL affecting carcass composition in sheep (Cockett et al, 2004)

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The double-muscling phenotype has been briefly discussed above in general terms, but not specifically for sheep. In sheep, MSTN translation is down-regulated by a miRNA target site created by a nucleotide substitution in the 3’ untranslated region (3’ UTR) of the MSTN gene (Callis et al., 2007). The ovine MSTN gene (*MSTN*) is located on chromosome 2 and a single nucleotide polymorphism (SNP) c*1232G>A has been described to increase muscle mass in Belgian Texel sheep in earlier studies and more recently an increase in carcass yield in NZ Romney sheep which will be discussed in detail later on. Additionally SNPs have been identified in promoter and intron 2 regions and are associated with muscling (Kijas et al., 2007). Exon 1- intron 1 variation exists in MSTN and this has been identified in many sheep breeds including the Romney over recent years

SNP c*1232G>A has been found in NZ Texel sheep and in one study lead to increased muscularity with the strongest association found for muscling and fatness traits in the leg (Johnson et al, 2005). Studies using Australian Texel sires demonstrates that the allele appears near fixation in the sample size of 116 individuals and has very little prospect for improving genetic gain in this breed. However for other sheep breeds this is not the case. In New Zealand Romney sheep for instance Hickford et al., (2010) revealed three haplotypes (A,B and C) defined by the variation in the exon 1-intron 1 region with the presence of A and B being associated with variation in lean meat production. Furthermore there are eight extended haplotypes of the ovine MSTN which was reported by Han et al., (2013) allowing a reasonable expectation that MSTN variation in sheep might also affect carcass characteristics (Han et al.,2015). For example having two copies of allele B can increase total carcass yield by 1.5 kg which a 17kg lamb carcass would cause an increase of 255g of meat (Hickford et al., 2010) which on an individual basis is small and in order to be beneficial the whole flock would have to be selected for this particular genotype (BB).

Callipyge (CLPG) is a muscular hypertrophy that is most pronounced in the muscles of the pelvic limb (Jackson et al, 1997a). Interestingly muscles from these lambs with the CLPG phenotype enlarge to differing degrees and not all muscles in the individual are affected (Cockett et al, 2004). In lambs with CLPG, the total weight of excised muscles (extensive survey of 19 dissected muscles) in the pelvic, torso and thoracic limbs was 42, 50 and 14% greater respectively with comparison to normal muscled half siblings (Jackson et al, 1997a). With comparison to double muscled animals, this muscular hypertrophy develops at approximately 3 weeks of age (Jackson et al, 1997b) therefore no increased risk of dystocia. Desirable production characteristics include higher dressing out percentages, larger loin eye areas, superior lean composition and higher leg scores have also been documented (Jackson et al, 1997c; Koohmaraie et al, 1995). Yields have been found to improve in leg, loin, rack and shoulder by 11.8, 4.7, 2.5 and 2.3% respectively compared with normally muscled lambs (Busboom et al, 1999). However in the United States the stigma with callipyge lambs being “tough” has limited selection. The cause of callipyge expressing lambs is caused by myofibre hypertrophy and callipyge responsive muscles exhibit larger average diameters for fast twitch oxidative glycolytic (FOG) and fast twitch glycolytic (FG) muscle fibres and smaller average diameters for slow twitch oxidative (SO) fibres (Cockett et al.,2004). In Callipyge expressing individuals the percentage of FG fibres is greater, while percentages of both SO and FOG have found to be relatively smaller. Therefore changes in myofibre in callipyge animals were strongly associated with FB fibres (increase in proportion and diameter in callipyge responsive muscles) (Cockett et al., 2004). Additionally as previously mentioned, development of callipyge affected muscles does not occur in utero, instead hypertrophy was only observed in 8 week old lambs and was not evident in 2 week old lambs (Carpenter & Cockett, 2000) therefore postnatal development of callipyge occurs (Cockett et al, 2004).

2.2.6 Foetal programming – importance of nutrition in skeletal muscle development

Maternal nutrition programs foetal development, including the development of skeletal muscle. This is due to the partitioning of nutrients. When compared with other organs, skeletal muscle has less of a priority in nutrient partitioning, and consequently the development of skeletal muscle is particularly vulnerable to nutrient availability (Zhu et al., 2006). For example Zhu et al., 2004 observed that a restriction of 50% of NRC requirements from day 28-78 days of gestation in sheep was shown to reduce the total number of secondary muscle fibres , as well as the ratio of secondary – primary muscle fibres. This was also observed in 2006, with the number of muscle fibres in 8 month old lambs born to dams which were nutrient restricted was less than those in control lambs with dams of adequate nutrition (Zhu et al., 2006). In a farming system early to mid-gestation nutrition needs to be adequate in order to reduce any potential that the growth performance of young stock is reduced. The results are very clear, any nutritional deficiency during the early – mid gestation period not only reduces muscle fibre number but also the muscle mass which would also consequently affect growth performance of the offspring (Du et al., 2009). It also important to note that in sheep skeletal muscle matures during late gestation (approximately 105 days) so consequently Nutrient restriction after this period has no impact on the number of muscle fibres, only the muscle fibre size. Greenwood et al., 1999 observed that litter mates compete for nutrients in twin pregnancies during late gestation and was found to affect the mass, but not the number of muscle fibres as demonstrated in figure (4). Additionally figure 4 also illustrates that nutrient restrictions also have the potential to reduce eating quality (decrease in marbling of the offspring) which is hghly sought after for high end premium markets. More importantly for this dissertation is that birth weight can also be reduced pre-birth due to reduced muscle fibre hypertrophy (Du et al., 2009).

2.2.7 Importance of nutrition in optimizing lean meat yield as well as birth weight

Emphasis should be based on providing adequate nutrition for ewes in early gestation right through to birth as nutrition can affect skeletal muscle development, lamb birth weight and growth postnatally. All muscles are not affected equally by variation in prenatal and postnatal nutrition and it's highly dependent on when nutritional constraints were imposed. Birth weight has a small but significant effect on muscle weight during postnatal growth in lambs, and this influence was mediated at least in part via effects on the amount of DNA in muscle and not the number of myofibres (Greenwood et al., 2000). The number of myonuclei in muscle is more important determinant of growth potential than myofibre number (Beermann., 1983).Myofibre number is established by 100 days of gestation after which foetal nutrient supply becomes an increasingly important determinant of foetal growth in sheep (Mellor., 1983). Nutritional constraints have also been found to have a profound effect on foetal programming and skeletal muscle development (Zhu et 2004; Du et al, 2009). Fewer nuclei in fibre of lambs that have severe foetal growth retardation, but have similar number of myofibres as in well grown foetuses at the completion of myogenesis (Greenwood et al, 2000) suggests that there is a buffering effect against the loss of structural and functional integrity due to inadequate fibre number with nutritional constraints. Instead a compensation period is required in order for the full complement of myonuclei to support requirements for normal muscle growth and mature muscle size. This is further demonstrated in low birth weight lambs which have less muscle DNA than their larger birth weight counterparts (Greenwood et al., 2000) indicating less myonuclei present. One of the bigger issues with nutritional constraints is how behind the individual is in normal lean meat development. Numerous studies, including Greenwood.,et al (2000) have demonstrated that permanent impairment of lean growth potential of sheep may only imparted by undernutrition during pregnancy, foetal programming has also illustrated this. Lower birthweights due to nutritional constraints during late pregnancy was shown to persist to at least 3 years of age (Schinckel & Short., 1961) as well as lower mature weights of offspring up to 5.5 years of age (Reardon & Lambourne., 1966; Gunn., 1977). Later studies conducted in 2006-2009 stressed the importance of early gestation nutrition in order to meet skeletal muscle development potential.In order to produce animals with adequate lean meat production nutritional constraints should be avoided from conception to birth to ensure lambs have the best chance for skeletal muscle development and subsequently lean meat production

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Figure 4: Effects of maternal nutrition on foetal skeletal muscle development. Nutrient restriction during mid gestation reduces muscle fibre numbers, but restriction during late gestation reduces both muscle fibre size and the formation of adipocytes. Diagram adapted from Du et al., 2009 and based on cattle, but dates have been estimated based on data from studies of sheep, rodents and humans

2.3 Production of superior carcasses (phenotype) including environment (nutrition) and key genes that affect muscle/ lean meat production

Short term – changing management strategies – different herbages

Changing management strategies such as change the lambing date to allow lambs extra time for growth could be beneficial however in the high country this is not practical due to cold temperatures and feed supply. If a farm was to change the lambing date then extra supplementary feed would either have to be grown or bought in, further increasing cost of production. Additionally there are different herbage options available such as herb and legume mixes (chicory, plantain, red and white clover) which can increase growth rates pre and post weaning and produce higher energy for lactating ewes and growing lambs. For example post weaning growth rates of lambs on herb/legume mixes was 247g/day (Goulding et al., 2011) compared with ryegrass and white clover pasture mixes (119g/day) (Goulding et al., 2011). Importantly phenotype is influenced by two factors, genotype and environment (P= G X E). It is unrealistic to focus solely on animals with high lean meat growth potential, if they are not being managed properly and adequate plans of nutrition are not provided in order for them to reach maximum production potential as discussed in the previous section

Long term = genetic selection to improve carcass traits select for genes that influence lean meat production and heavier birthweights

Sheep population in NZ has a large amount of variation for many traits and there is considerable potential to discover, identify and select animals that are superior for improving carcass quality (Yang. 2014). Key production traits such as growth rate, lean meat yield and carcass composition all show moderate heritability of 20 to 35% (Safari et al., 2003) therefore potential for improvement in these traits would be possible, Selection for higher quality carcasses is only one side of the equation, selection for animals with a smaller mature weight (less maintenance costs and reach puberty faster) as well as heavier lamb(birth weight) that meet target weights quicker (faster growth rates) post weaning.

2.3.1 Carcass traits

Weight of the carcass is a major determinant of carcass value (Han., 2012) however other traits are also gaining in importance such as lean meat yield.In terms of economic value of lamb both growth rates and carcass traits are key determinants (Han., 2012) and need to be focused on in order for the NZ sheep industry to meet stringent export standards. Variation in MSTN is already being commercially used in the sheep industry to increase lamb carcass weight and muscle yield (Pfizer Animal Health NZ; Lincoln University Gene Marker Laboratory; Han. 2012). It is already well understood that MSTN is associated with improved carcass traits (Clop et al., 2006; Hadjipavlou., 2008; Johnson et al., 2009); Hickford et al., 2010). While Texel sheep with an already high frequency of MSTN will most likely limit contribution to any further gain genetically in this breed this is not the case for Romney sheep.

2.3.2 Variation in carcass and growth traits with different MSTN haplotypes

As previously discussed Romney sheep have three haplotypes (A, B and C) due to variation in the exon-intron region. Haplotypes A and B were associated with variation in the production of lean meat (Hickford et al., 2010). However interestingly the number of MSTN haplotypes in Romney sheep is a moving target, five MSTN haplotypes (H1, H2, H3, H5 and H7) were identified in 2012 (Han., 2012) 2 indicating that a greater diversity exists than what was previously thought. This could be to do with study size, a greater sample size was used where the 5 haplotypes were discovered, compared with 3 haplotypes discovered when a smaller portion of the gene was focused on.

2.3.3 Effect of different haplotypes on carcass traits

Presence of H1 was found to be associated with increased loin yield, leg yield, total yield and proportion yield in both half-sib and pooled data analysis by Han (2012) demonstrating an increase in muscularity. For NZ Texel sheep for example an increase in *M. lomgissimus* muscle was observed (Johnson et al.,2009) as well as in Charollais sheep (Hadjipavlou et al., 2008). Heavier fore quarters was also observed in Belgian Texel sheep (Clop et al., 2006) illustrating the effect H1 can have on the carcass. An individual with a genotype of H1H5 in Romney sheep was shown to have higher loin, leg and total yield (Han., 2012). In Romney sheep muscling was only increased by 1% when H1 was present which was disappointing, compared to other studies on other breeds of sheep on MSTN. Pfizer claimed a 5% muscling increase in the leg and rump with one or two copies of MSTN. Possibly the disappointing result could have been due to only have a heterozygous form (animals only carrying 1 copy).

H2 has been associated with lamb growth traits, lambs in the Doughboy 41/06 sire line which inherited H2 haplotype had a heavier draft weight of 3.63 kg and were approximately drafted 23 days earlier (Han., 2012). Growth rates of lambs are crucial for farm productivity in getting lambs off the property earlier and be able to be slaughtered at times when the prices are higher (Pre- Christmas lamb market). However H2 has been found to be associated with decreased leg, loin and total yield of lean meat (Hickford et al., 2010). However in Han thesis the reduction of loin and total yield was found not to be associated with H2 leading to conflicted results and potential for further study.

H3 is associated with some variation in carcass traits including a positive effect on hot carcass weight when present in heterozygous form with H1, H2, H5 and H7 (Han., 2012)and when present with H2 and H5 (heterozygous form) was found to be associated with higher growth rates to weaning, leg and total yield. Therefore H3 is not only affecting growth rates to weaning in lambs that inherit H3 but also increased yield in carcass traits (leg and total) (Han., 2012)

H5 in homozygous form has been associated with adverse effects on growth rate to weaning and carcass traits (loin,leg and total yield) (Han., 2012) in comparison to other haplotypes present in the Romney breed. However it should be mentioned that there has been a failure to detect a relationship between H5 and carcass traits which were reported by Hickford et al., (2010) and Han, (2012) had only just detected it which further supports that there is a negative effect of H5 on meat yields but this needs further research to be concluded.

H7 has been thought to be associated with decreased muscularity (Han., 2012) and is believed to affect the function of MSTN. Haplotype H7 results in an amino acid substitution of Glu/Gly. This has been found to be the only nucleotide substitution identified in the coding region of MSTN in NZ Romney sheep (Zhou et al., 2008) and may in fact affect the function of MSTN pro-peptide (Tellgren et al., 2004) and consequently affect skeletal muscle growth. Han., (2012) discovered decreased leg yield compared to other haplotypes (H2, H3, and H5). H7 is suggested to have an effect on growth but at the expense of meat yield (increased bone weight and not meat weight) (Han., 2012) therefore a greater carcass weight but no meat yield benefit. However more research is required to determine exactly what its effect on carcass traits are considering that there is a low frequency of H7 in sire lines used in Han (2012) and H7 was not detected in Coopworth or Perendale sheep which are based on Romney genetics could suggest very little value of the presence of H7 in production traits.

Table 1 illustrates haplotype frequency in different sheep breeds in NZ and gives a good indication on what haplotypes are present in certain breeds. The Romney had H2 as the highest percentage (63.19%) followed by H3 (22.22%), H5 (13.89%) and H7 (0.69%) respectively. Interesting to note, H1 is not represented in the Romney breed, however in Texel’s 56.25% of 10 sampled sheep had H1 haplotype.

Table 2: Frequencies of haplotypes identified (%) in Han (2012) of different NZ sheep breeds including dual purpose, meat, wool and cross-bred demonstrating haplotype frequency in myostatin.

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The increase in yield on the carcass is only valuable economically if it is in the right location. High value cuts occur in the loin, back leg and shoulder. In 2011 this increase in yield would have led to $1.00 more in carcass value, and overall $27 million extra income for the NZ sheep industry (Han.,2012). So if H1 genotype was selected for then this selection would have economic importance, if the whole industry selected for it as on an individual farmer basis the change will be small.

2.4 Using Birth weight and fecundity to increase flock productivity

2.4.1 Birthweight

Significant differences have been found to exist between breeds of livestock in mean birthweights, mature bodyweights and potential optimal rates of live weight gain over given age intervals (Wardrop, 1968). Relating back to foetal programming and environmental influences of the developing lamb, it has been demonstrated that these three important characteristics can be affected significantly by the plane of nutrition (Wardrop.,1968). In sheep especially a low plane of nutrition during the last third of pregnancy can result in below average birthweights (Wallace., 1948). Consequently nutrition has a critical role in determining the birth weight of lambs. The importance of birth weight is due to it being the first indicator of the growth potential of the lamb and is considered a key determinant of animal growth rate, particularly during pre-weaning growth (Farokhad et al., 2011). In terms of selection for different MSTN haplotypes to improve growth in NZ Romney sheep, H1 carrying lambs were found to have increased tailing weights and draft weights in Fernvale line 1106.02 (Han.,2012). Positive correlations between birthweight, tailing, weaning and growth rate to weaning/draft weight were also found (Han.,2012) which also strongly suggests that selecting for increased birthweight along with the presence of H1 MSTN would lead to improvement in Romney growth.

Birth weight has been found to be moderately heritable with 19% heritability for dual purpose breeds such as Romney (Fogarty., 1995; Safari et al., 2005). Additionally weaning weight was also found to have moderate heritability of 18-20% 0.18-0.20 and post weaning weight of 26% and end adult live weight of 31% heritability (Fogarty., 1995; Safari et al., 2005). Therefore breeding for traits such as birthweight, weaning weights (pre and post) and adult live weight is possible in Romney sheep with moderate heritability estimates. However selecting for birth weight should be carried out with caution. Selecting for MSTN variation has been associated with an increased risk of birthing difficulty, which has been observed in cattle (Wiener et al., 2002) and high death rates were found in animals with homozygous double muscling (loss of function variation) (Wiener et al., 2002). This is often caused by the increase in calf birthweight (Esmailizadeh et al., 2008) as well as being physically larger (shoulders). Because Romney sheep are used in many different areas of NZ including the high country where it is impractical to monitor and or always assist the birthing process, it would be unrealistic to change the Romney from an easy care breed to something that needs constant monitoring for lambing .It is well understood that lambs over 5.5kg at birth are considered vulnerable to difficult birth or dystocia (Gourt et al., 2010) , whereas the H1 in Fernvale 1106.02 sire line had a mean birth weight of 5.31 kg bordering on the line of birthing difficultly in the literature

2.4.2 Importance of birthweight for lamb survival

Birthweight is the most major factor influencing survival of lambs (Bradford., 1972). For instance survival and birthweight are related in a curvilinear manner (Hinch et al., 1985). This relationship is based on heavy birthweights being associated with dystocia and losses at low birthweights of the greater susceptibility of small lambs to cold environments (Alexander., 1964; Hinch et al., 1985). Dystocia is a major cause of lamb death in singles, and the incidence increases with birth weights over 3.6kg. At high birth weights Dystocia is most likely caused by an incompatibility in size between the maternal pelvis and the lamb at birth (foetus-pelvic disproportion) (McSporran & Fielden., 1977; Dalton et al., 1980). Dystocia can also be the cause of death for lower birth weights as well in multiple- born lambs. This is possibly caused by weak lambs and ewes, with the ewe having poor uterine contractions consequently causing the birth to be slow (Dalton et al., 1980).Selection focused on prolific sheep which have higher ovulation rates and hence resulting litter sizes, a clear understanding of what influences lamb birthweight is critical. As the proportion of multiple born lambs increases in a flock, the impact of dystocia on survival declines and the importance of low birthweight increases (Hinch et al., 1985). Multiple born lamb survival increases with higher birthweights particularly between the 1-3.5 kg range (Hinch et al., 1985). The risk of lower birthweight lambs is decreased cold tolerance and are more susceptible to neonatal mortality (Gardner et al., 2007). The literature is very clear on the range of maximum survival in lamb birth weights with the highest survival rates occurring within a range of 3.5-5.5 kg (Dalton et al., 1980). Outside of the range, with birth weights below 3 kg and above 5.5 kg the chances of survival are low (Dalton et al., 1980).Selecting for birth weight would not only improve growth rates but also improve lamb survival rates.

2.4.3 Birth weight and litter size

Birth weight is greatly affected by litter size, for instance twins were 87%, triplets 75% and quads 62% of the average singleton weight in Mule ewes (Gardner et al., 2007). The error term for birth weight was found to decrease with increasing litter size which suggests that the reduced uterine space limits variance in birth weight (Gardner et al., 2007). Birth weights of lambs from well-nourished ewes decrease as litter size increases (Freetly & Leymaster., 2009) therefore suggesting that decreased birth weight in multiple born lambs is not solely a function of maternal nutritional factors. However with the decreasing rate of increase in litter birth weight with increased litter size could suggest that foetal growth is increasingly being restricted as the litter size increases (Freetly & Leymaster., 2004). This could be because nutrient availability to the foetuses may become restricted with multiple foetuses. There are two reasons for this being cited in the literature, 1) nutrient availability to the foetus may result from a reduction in available nutrients presented to the foetus (deficit of maternal nutrition) or 2) the delivery of nutrients to the foetus via placental transport. In twins, umbilical blood flow has been found to be lower than those of single foetuses (James et al., 1972) and consequently increasing litter size results in decreased cotyledon number, weight and surface area (Kaulfub et al., 2000). More importantly especially in regards to this honours dissertation is that a reduction in placentome number and weight also results in a decrease in skeletal muscle hypertrophy during late gestation (McCoard et al., 2000) which could affect meat yield in lambs being sent for slaughter.

2.4.4 Sire effects on birth weight

Spermatozoan midpiece length (MPL) has been reported to have a positive correlation with mature body weight in mice (Beatty., 1969). This had been hypothesised that an increase in mitochondrial content (with an increase in MPL) might consequently cause a higher rate of oxidative phosphorylation, which in turn could affect a wide array of characteristics such as body weight (Saoud et al., 1984). In Holstein bulls it had been observed that there was variation in the average MPL and this seemed highly heritable and appeared to be negatively correlated with predicted differences for dairy production traits (Lukefahr & Hohenboken., 1981). However in sheep, there was no significant difference in within breeds and economically important traits in MPL (Saoud et al., 1984) and this is contradictory to findings in previous studies mentioned earlier.

Birth weight has been found to be significantly affected by the breed of sire. For instance the average birth weights of Suffolk sheep were 5.04 kg, 4.93 kg for Texel and 4.88 kg for Charollais sired lambs respectively (Yaqood et al., 2004) as further illustrated in table (2). Results of Kremer et al (2004) was also in agreement, in which when Texel sires were used, the resulting lambs were 0.54 kg more than other crosses and 1.2 kg more than purebred Corriedale lambs which was highly significant in carcass yield. In another study where three genotypes were used (Mis (1), Wurttemberg (2) and Ile de France (3) in which the average birth weights varied from 4.40 for genotype 1, 4kg for genotype 2 and 4.50 kg for genotype 3 (Caro Petrovic et al., 2013) while not a statistically a significant difference, there was obvious variation in lamb birth weights due to different sires and genotypes. Further literature searches also agree with the above results with Cloete et al., (1992) stating the significant effect of sire on the birth weight of lambs. Furthermore Olivier et al., (1987) found that the variance term between sire was also significant for birth weight and variation was found between sires for type traits. Finally early on in the literature, Kincaid., (1943) concluded that a sire could influence only the hereditary characters of lambs and that in certain rams within each breed, characteristics could be transmitted to lambs which influenced birth weight. This conclusion further reinforces that sires can be selected for birth weight and growth rates for eBV estimates and them having an effect on the resulting offspring.

Table 3 Effect of year, breed of sire and sex of lambs on birth weight

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Adapted from Yagood et al (2004).

Another important aspect which influences lamb birth weight is gestation length (figure 4). Each genotype had observed gestation lengths, with genotype 1 having a range of 144-153 days, genotype 2 with 144-151 days and genotype 3, 144-151 days respectively (Caro Petrovic et al., 2013). The general trend in this study demonstrated that the shorter the gestation length, the lighter the lamb birth weight was. The opposite is also true, the longer the gestation length the heavier the lamb is at birth as illustrated by genotype 1 especially. However it seems that there is a cut-off point after 153 days (Caro Petrovic et al., 2013). Other studies have also reported that gestation length can affect lamb birth weight. For instance ewes with heavier lambs at birth have been found to have longer gestation lengths (Thrift & Durr., 1972). Sex of the lamb has also been discussed as having an influence on not only birth weight but also gestation length. However the sex of the lambs has been observed not to have a significant effect on the gestation length with only single males having one day extra in utero than single females. (Thrift & Durr., 1972).

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Figure 5: Effect of gestation length (days) on birth weight (body weight at birth, BWB-kg) adapted from (Caro Petrovic et al., 2013).

As previously discussed, foetal growth and birth weight are regulated by the genotype of the foetus, maternal genotype, maternal nutrition and the external environment (Oldham et al., 2011). In a statistics model if sire effects need to be fixed for birth weight it has been found that the effect of sire genotype and gestation length interact between subject effects such as sire* gestation length, sire*sex, gestation length*sex, sire*gestation length*sex highly and significantly affected the birth weight of lambs (Caro et al., 2013). This is crucial for understanding the influencing factors that affect birth weight and changes will be able to be made in management and breeding programs. The interactions described here will be a good indicator to be acquainted more on the influence of a particular trait. For instance selecting for heavier birth weights in lambs could increase the gestation length in the ewe.

2.4.5 Sire effects on growth and carcass traits

Pre-weaning growth potential of a lamb is affected by whether the lamb was born or reared as a single or multiple (Safari et al., 2007; David et al., 2011). Additionally birth type can account for up to 31% of the phenotypic variance in pre weaning growth (Hagger., 1998) hence this would need to be adjusted for in genetic models, especially litter size as litter and permanent environment simultaneously contribute to the variation of early lamb growth traits (Hagger., 1998) however litter size is much more important to correct for in breeding values (Hagger., 1998).

Heritability estimates (H_2) gives what proportion of the variation is due to genetics or the environment with values ranging from 0.0 (genes are not contributing, environment is) to 1.0 (genes are the only contributing factor). For Romney sheep these have been composed into a table (5). All traits listed below are both environmentally and genetically influenced. Therefore animal selection can occur but the environment also has a huge influence on the phenotypes. This can be further described with birth weight which as previously been discussed in detail. With an H_2 estimate of 0.29 (Blair., 1998) it can be selected for in breeding programmes, however it is even greater influenced by the environment such as maternal live weight at mating (feed supply) and supply of nutrients throughout pregnancy. Lean muscle in the carcass has an H_2 estimate of 0.37 in Romney sheep (Waldron et al, 1992), while eye muscle is even greater with 0.63 (Waldron et al, 1992) hence genetics play a major role in carcass composition in sheep and can be selected for. However environmental influences and the limitations they cause must not be over looked as this is further illustrated by phenotype = genotype X environment.

Table 4: Heritability estimates of growth and carcass traits in New Zealand Romney sheep.

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Adapted from Fogarty (1995)

Conclusion

The New Zealand red meat sector is the second largest export earner after dairy products (MIA,2016) and sheep meat exports were worth $3 billion in 2016 (MIA, 2016). Therefore improving productivity is vital to increasing export volume. NZ sheep industry is faced with constant challenges of meeting consumer expectations hence carcass improvement must be at the forefront of sheep breeding programs. Skeletal muscle represents a large proportion of the total carcass, in sheep this is 50-60% of the total carcass weight (McCourd, 1998). Development of skeletal muscle is crucial to improve carcass yield and quality. Development of skeletal muscle occurs in utero and can be influenced by nutrition (maternal environment and foetal programming) and genetics. Nutrition is crucial during pregnancy due to early initiation of muscle development which can affect post-natal lamb growth if nutrition is limiting during this development period. Number of muscle fibres can only be altered in utero due to myoblast hyperplasia, while size of muscle fibres occurs postnatally from cellular hypertrophy due to an increase in DNA and protein content (Kang et al., 1985) without any further increase in the number of muscle fibres (Smith, 1965). Consequently nutrition will affect the potential of the developing lamb postnatally and can cause not only a reduction muscle fibre number but also muscle mass which will reduce lamb birth weights and affect growth performance of offspring (Du et al., 2009).

Skeletal muscle can be altered by specific genetic mutations such as myostatin which increases muscle hypertrophy and subsequently increases carcass yield. Different forms of the mutation have been observed in Romney sheep and have different effects on carcasses such as yield, composition and lamb birth weights. These mutations have shown when the right form is selected for to be beneficial for sheep breeders to increase carcass yields. As well as alerting to the fact that genes can influence development of skeletal muscle and change carcass composition which could be of benefit to meeting consumer expectations of leaner carcasses and less fat. Birth weight is crucial for lamb survival especially cold tolerance and has also been linked in the literature to influencing growth rates. Birth weight is affected by litter size mostly due to maternal factors such as reduced uterine spare and partitioning of nutrients. Finally the importance of animal selections is emphasised through sires having a significant effect on birth weight of lambs, growth rates and carcass traits demonstrating investment of good quality rams from top proven sire lines will increase lamb production.

Few studies have been carried out on the influence of lamb birth weight on carcass yield and if there is a direct relationship. The literature has demonstrated how crucial lamb birth weight is, but is selecting for greater lamb birth weights also have a production benefit over and above survival. Hence there is need to undertake this research in order to provide confident recommendations to farmers on improving ewe nutrition to optimize lamb birth weights which will increase financial gain due to increased lean meat production.

Chapter 3

Materials and Methods

Data used was from South Island Romney meat data (2009-2016 lambs) which were born and raised on one farm. The lambs were progeny of 17 independent sire lines and these were recorded beside each individual lamb in the data set. Sampling of the lambs occurred as early as birth (birth weight) then they were weighed again at tailing (approximately 3 weeks) and then weaning (3 months). Other details such as gender, sire and birth rank (single, twin or triplet) was recorded at birth. For carcass trait data, male lambs were slaughtered once they reached a target live weight of 36 kg for meat production.

Results section:

Data was adapted from the South Island Romney meat data of lambs from 2009-2016. First primary sorting was carried out, getting rid of individuals which did not have any meat trait data. Secondly once this was done, the data was then gender sorted to remove ewes from the data set due to only having a small number of ewe lambs which were slaughtered and also to remove any gender effects from the statistical analysis. Final data consisted of 2521 Romney ram lambs.

Data was then compiled onto one sheet for all years with data (some years were missing meat trait data and were removed) then averages and standard deviations were calculated using excel 2013 software for meat traits for both years and overall.

After this correlations between meat traits and birth weight/ weaning weight and final weight was calculated using SPSS v24.0 and tests between subjects was also calculated using this software. Excel 2013 was used for figure generation and basic descriptive statistics.

Chapter 4

Results

4.1 Interaction of lamb birth weight on growth rate, weaning weight, final weight (WT4 or WT5) and carcass traits (Leg, loin, shoulder and total yield)

Birth weight and lamb growth rates were found to be interrelated, with the heavier the birth weight, the greater the growth rate (figure 6). Low birth weight (2.75 kg) grew at 81.25 g/day, medium birth weight (5.88 kg) at 241.28 g/day and high birth weight (9.50 kg) at 366.66 g/day respectively.

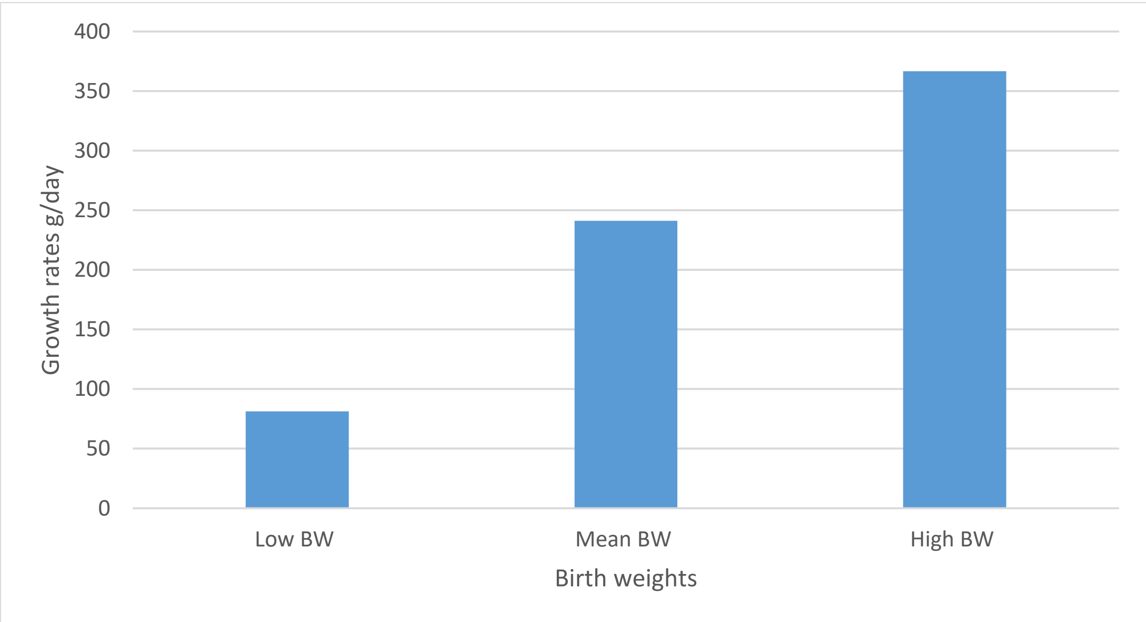

Figure 6: Birth weight and lamb growth rate

Birth weight and weaning weight were found to have a moderately strong (0.467) positive correlation as further illustrated in figure 7. Therefore generally lambs that had a greater birth weight had a heavier weight at weaning. This effect is statistically significant ($p<0.001$). The correlation with final lamb end weights (WT 4 or WT 5) was 0.152 and 0.242 respectively (table 5) which was a weak positive relationship and this result was also significant (p< 0.001).Meat yield traits (leg, loin, shoulder and total yield) had a weak but positive correlation with lamb birth weight. However the only relationships which were significant was shoulder and total yield (p<0.001) respectively. Percentage leg and loin had a weak negative correlation with birth weight, however percentage leg yield was the only significant relationship (p<0.001). Percentage of shoulder yield had a weak positive correlation with birth weight and this relationship was also significant (p<0.001).

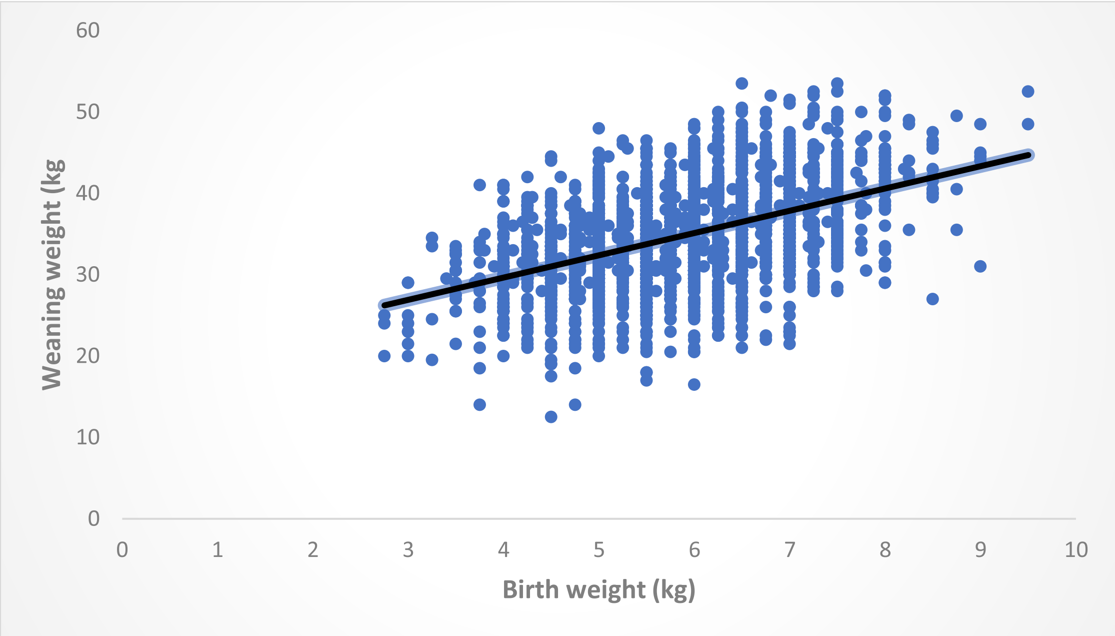

Figure 7: Correlation of birth weight and weaning weight (kg)

Table 5: Association of lamb birth weight with weaning and final weight (Wt 4 or 5) and carcass traits (leg, loin, shoulder and total yield) and percentage of yield (leg, loin and shoulder).

		W-Wt	WT 4	Wt 5	LEG YLD	LOIN YLD	SHLD YLD	TOTAL YIELD	%YLD LEG	%YLD LOIN	%YLD SHLD
Birth Wt	Pearson Correlation	0.467	0.152	0.242	0.018	0.055	0.147	0.078	-0.111	-0.021	0.118
	Sig (2 tailed)	**0.000**	**0.000**	0.013	0.371	0.006	**0.000**	**0.000**	**0.000**	0.287	**0.000**
	N	2477	1503	104	2521	2521	2521	2521	2517	2517	2517

[1] p<0.005 are in bold

4.2 Interaction of lamb weaning weight on final lamb weight (WT 4 or WT 5) and carcass traits (leg, loin, shoulder and total yield).

Lamb weaning rate was found to have a moderately strong positive correlation with end lamb weight (WT 4 and WT 5) with 0.413 and 0.546 respectively (table 6) and both these correlations were highly significant (p<0.001) as further illustrated in figure 7. Hence lambs that are heavier at weaning are also heavier in final weight. For carcass traits a weak positive correlation was found between weaning weight and shoulder yield (0.353) and this was also highly significant (p<0.001) however all other traits except for percentage of leg which was a moderate negative correlation (-0.346) had very weak correlations with lamb weaning weight, and all results were significant (p<0.001) except for leg and percentage of loin yield. Special note with the two different weaning rates, WT 4 was lambs that were sent off farm earlier (higher proportion hence greater sample size) and WT 5 were lambs that took longer to reach target live weights of 36kg.

Table 6: Association of lamb weaning weight with birth and final weight (Wt 4 or 5) and carcass traits (leg, loin, shoulder and total yield) and percentage of yield (leg, loin and shoulder).

		WT 4	WT 5	LEG YLD	LOIN YLD	SHLD YLD	TOTAL YIELD	%YLD LEG	%YLD LOIN	%YLD SHLD
WEANING WT	Pearson Correlation	0.413	0.546	0.015	0.179	0.353	0.190	-0.326	0.039	0.275
	Sig. (2-tailed)	**0.000**	**0.000**	0.400	**0.000**	**0.000**	**0.000**	**0.000**	0.050	**0.000**
	N	1732	143	2972	2972	2972	2972	2503	2503	2503

[1] p<0.005 are in bold

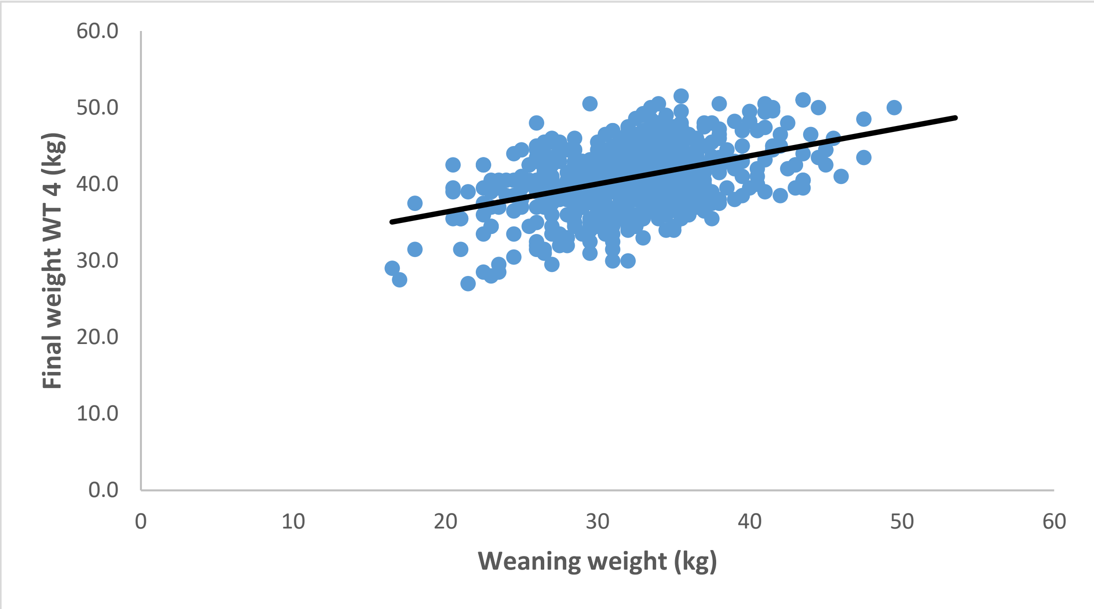

Figure 8: Correlation between weaning weight and final weight WT 4 (kg)

4.3 Interaction of final lamb weight (WT 4 or WT 5) and carcass traits (Leg, loin, shoulder and total yield)

Final lamb weight (WT 4) (table 7) was found to have a weak negative correlation with leg yield and weak positive correlation with loin, shoulder and total yield and this result (table).However percentage leg had a moderate negative correlation (-0.374) with lamb final weight and percentage loin yield had a moderate positive correlation (0.306). Percentage shoulder yield had a weak positive correlation with lamb final weight. All correlations in table 7 were statistically significant ($p<0.001$) except for total yield which was ($p>0.005$)

Additionally for lamb final weight (WT 5) (table 8) there was a weak negative association between final weight and leg yield (-0.297) and this was highly significant ($p<0.001$). Loin yield showed a positive but weak relationship (0.315) which was also highly significant ($p<0.001$). Total yield was weakly negative and this was not significant ($p>0.005$). Shoulder and total yield was similar to WT 4 (table) however these correlations were statistically non-significant (p>0.005). Percentage of leg yield had a moderate to strong negative correlation while loin yield had a positive moderate correlation with lamb final weight. Both of these were statistically significant (p<0.001). Shoulder yield percentage had a very weak positive correlation and this was not significant (p>0.005).

Table 7: Association of lamb end weight (WT 4) with birth, weaning weight and carcass traits (leg, shoulder and total yield) and percentage of yield (leg, loin and shoulder).

		LEG YLD	LOIN YLD	SHLD YLD	TOTAL YIELD	%YLD LEG	%YLD LOIN	%YLD SHLD
WT 4	Pearson Correlation	-0.120	0.189	0.151	0.055	-0.374	0.306	0.136
	Sig. (2-tailed)	**0.000**	**0.000**	**0.000**	**0.020**	**0.000**	**0.000**	**0.000**
	N	1767	1767	1767	1767	1514	1514	1514

Table 8: Association of lamb end weight (WT 5) with birth, weaning weight and carcass traits (leg, shoulder and total yield) and percentage of yield (leg, loin and shoulder).

[1] p<0.005 are in bold

		LEG YLD	LOIN YLD	SHLD YLD	TOTAL YIELD	%YLD LEG	%YLD LOIN	%YLD SHLD
WT 5	Pearson Correlation	-0.297	0.315	0.051	-0.012	-0.635	0.651	0.031
	Sig. (2-tailed)	**0.000**	**0.000**	0.537	0.886	**0.000**	**0.000**	0.757
	N	148	148	148	148	104	104	104

[1] p<0.005 are in bold

4.4 Interaction of total yield (lean meat production) on carcass traits (leg, loin and shoulder) and percentage of yield (leg, loin and shoulder)

Total yield (lean meat production) had a very strong positive correlation with leg yield (0.900), a strong positive with loin yield (0.882) and a strong relationship with shoulder yield (0.784) respectively in table 9. All three of these results were highly significant (p<0.001). There was a very weak positive correlation between total yield and percentage of yield in leg and loin. While percentage of yield in shoulder was weakly negative. However all were statistically significant (p<0.001).

Table 9: Association of lamb lean meat yield (total yield) with birth, weaning weight and carcass traits (leg, shoulder and total yield) and percentage of yield (leg, loin and shoulder).

		LEG YLD	LOIN YLD	SHLD YLD	%YLD LEG	%YLD LOIN	%YLD SHLD
TOTAL YIELD	Pearson Correlation	0.900	0.882	0.784	0.122	0.139	-0.213
	Sig. (2-tailed)	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
	N	3030	3030	3030	2552	2552	2552

[1] p<0.005 are in bold

4.5 Effects of year, ram, birth weight, weaning weight and lamb final weight (WT 4 or WT 5) on lean meat yield production, leg, shoulder and loin yield

Lean meat yield (total yield) in lambs is significantly affected by the sire ($p<0.001$) with Gatton Park 29/06 sired lambs having the lowest lean meat yield of 52.20% compared with Ramhill 322/11 with 57.74% respectively (appendix B.2). Weaning weight ($p<0.001$) was also highly significant (table 10) in influencing total/ lean meat yield.

For shoulder yield (table 12) year was found to have a significant effect ($p<0.002$) and sire ($p<0.001$) with Snowlea 192/02 sired lambs having 16.21% shoulder yield compared with Ramhill 322/11 sired lambs with 18.41% respectively (appendix B.2). Weaning weight was also found to have a significant effect on shoulder yield ($p<0.001$). While birth weight and weaning weight of lambs did not have an effect which was significant on the shoulder yield of lamb carcasses.

For leg yield (table 11) only sire and final lamb weight had a significant effect on the yield of leg ($p<0.001$ and $p= 0.002$) respectively. Offord 414/01 sired lambs were found to have the smallest leg yield with 20.47% and Ramhill 322/11 sired lambs had the greatest with 23.55% (appendix B.2) respectively. The effect of year, birth weight and weaning weight of lambs did not have a significant effect on lamb leg yield.

For loin yield (table 13), year and birth weight did not have a significant effect. However sire was significant ($p<0.001$) with Doughboy 45/04 sired lambs having the smallest loin yield (13.68%) compared with Ramhill 322/11 sired lambs having the greatest loin yield of 15.79% respectively (appendix B.2). Additionally weaning and final lamb weight had a highly significant effect on lamb loin yield ($P<0.001$).

Birth weight (table 14) was found to be significantly affected by sire ($p<0.001$) however year was found not have a significant effect ($p<0.005$). Figure 9 and (refer to appendix B.1) Gatton Park 29/6 had a lowest mean birth weight in lambs (5.10kg) and Ramhill 322/11 had the highest mean birth weight with 6.65 kg average.

Table 10: Test of between subject effects (Univariate analysis of variance) of total yield (lean meat production) of lamb carcasses against year, sire, birth weight, weaning weight and final weight

LEAN MEAT	TYPE III SUM OF SQUARES	DF	MEAN SQUARE	F	SIG.
YEAR	59.685	5	11.937	2.154	0.057
RAMID	1307.314	73	17.908	3.231	**0.000**
B WT	0.782	1	0.782	0.141	0.707
W WT	84.720	1	84.720	15.286	**0.000**
WT4	9.719	1	9.719	1.754	0.186

[1] p<0.005 are in bold

Table 11: Test of between subject effects (Univariate analysis of variance) of leg yield against year, sire, birth weight, weaning weight and final weight (WT 4).

LEG YIELD	TYPE III SUM OF SQUARES	DF	MEAN SQUARE	F	SIG.
YEAR	12.549	5	2.510	1.975	0.080
RAMID	253.877	73	3.478	2.737	**0.000**
B WT	2.873	1	2.873	2.260	0.133
W WT	1.248	1	1.248	0.982	0.322
WT 4	6.928	1	6.928	5.452	**0.020**

[1] p<0.005 are in bold

Table 12: Test of between subject effects (Univariate analysis of variance) of shoulder yield against year, sire, birth weight, weaning weight and final weight (WT 4).

S YIELD	**TYPE III SUM OF SQUARES**	**DF**	**MEAN SQUARE**	**F**	**SIG.**
YEAR	12.347	5	2.469	3.751	**0.002**
RAMID	171.100	73	2.344	3.560	**0.000**
B WT	0.000	1	0.000	0.001	0.979
W WT	27.213	1	27.213	41.333	**0.000**
WT 4	1.876	1	1.876	2.849	0.092

[1] $p<0.005$ are in bold

Table 13: Test of between subject effects (Univariate analysis of variance) of loin yield against year, sire, birth weight, weaning weight and final weight (WT 4).

LOIN YIELD	**TYPE III SUM OF SQUARES**	**DF**	**MEAN SQUARE**	**F**	**SIG.**
YEAR	5.296	5	1.059	1.688	0.134
RAMID	106.497	73	1.459	2.324	**0.000**
B WT	0.624	1	0.624	0.994	0.319
W WT	8.207	1	8.207	13.076	**0.000**
WT4	19.225	1	19.225	30.633	**0.000**

[1] p<0.005 are in bold

Table 14: Test of between subject effects (Univariate analysis of variance) of birth weight against year and sire.

BIRTH WEIGHT	TYPE III SUM OF SQUARES	DF	MEAN SQUARE	F	SIG.
RAMID	193.348	83	2.329	2.594	**.000**
YEAR	15.348	6	2.558	2.848	.009

[1] p<0.005 are in bold

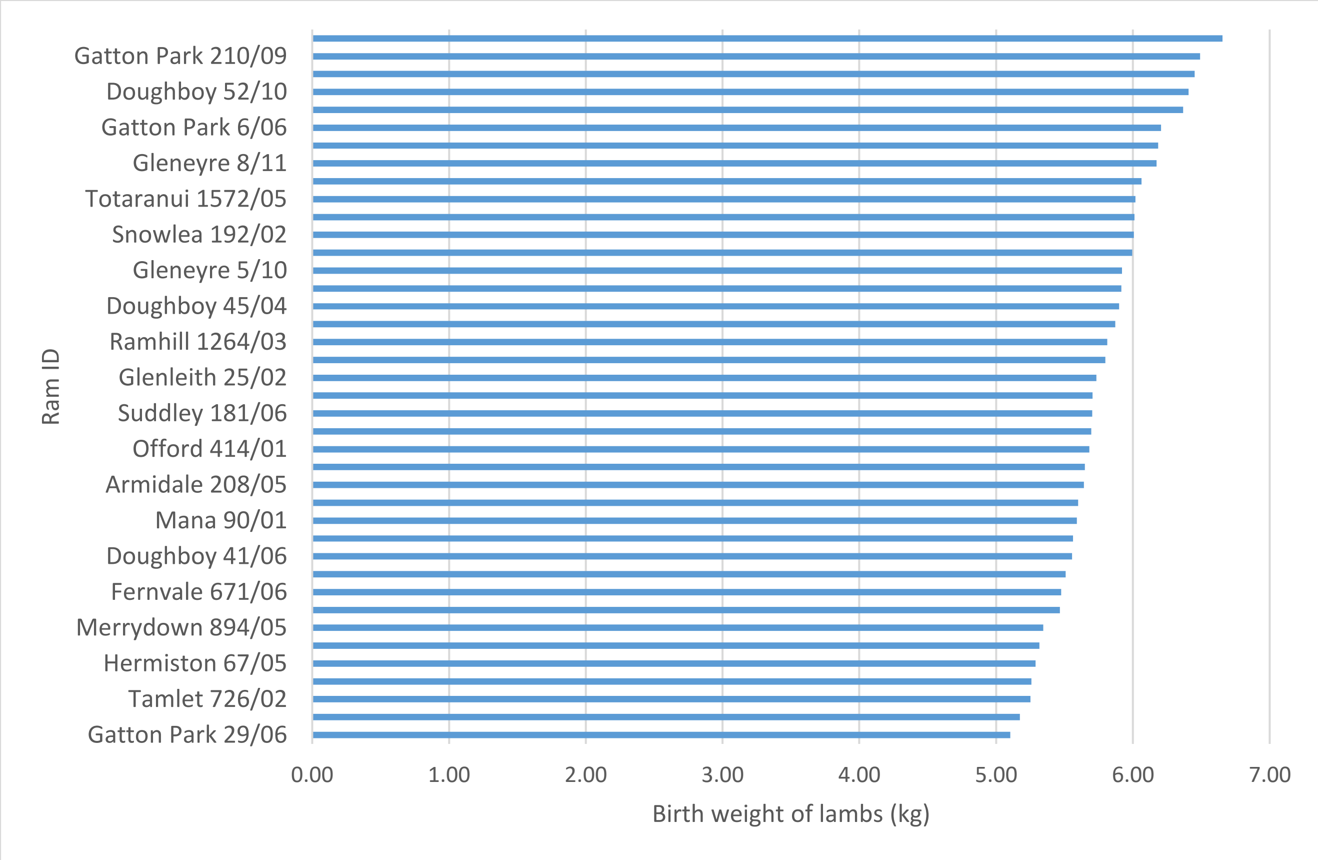

Figure 9: Ram id and birth weight of lambs (kg) based on top 40 rams that had sired more than 30 lambs in study.

Chapter 5

Discussion

In lamb production systems birth weight is the most major influencing factor affecting the survival of lambs (Bradford, 1972; Hinch et al., 1985) hence the significance for using it in selection based approaches. Additional to this it was observed in this study that birth weight was found to have a strong positive correlation with lamb weaning weight. Further analysis has also demonstrated that birth weight has a strong impact on lamb growth rates as illustrated in figure 6. Lambs that had a heavier birth weight grew faster therefore the strong correlation with weaning weight. These results were in agreement with numerous other studies who also observed significant effects of birth weight on lamb growth (Penning et al., 1980; Villette & Theriez, 1981).

This study also highlighted the importance and influence of genetics in lamb growth traits with birth weight, weaning weight and lamb final weight all being significantly influenced by sire. Again these findings were in agreement with previous studies associating the effect of ram genotype especially on lamb birth weight (Cloete et al., 1992; Olivier et al., 1987; Caro Petrovic et al., 2013).

Interactions between birth weight, weaning weight and lamb final weight with carcass traits were identified. While correlations with birth weight and carcass traits were weak to moderately positive these relationships were highly significant and illustrated that lamb birth weight can also affect shoulder, loin and lean meat production however a negative relationship with leg yield was observed. Weaning weight showed similar positive relationships and so did final weight of the lamb which was as expected. Effect of sire was also highly significant with carcass traits for example lean meat production in lambs varied by choice of sire, with Gatton Park 29/06 sired lambs having the lowest lean meat yield of 52.20% compared with Ramhill 322/11 sired lambs with 57.74% respectively. Therefore selection of rams for use in lamb production systems could be crucial in increasing productivity.

5.1 Birth weight – effect on lamb growth rates, weaning weight and final weight

Birth weight in this study was found to influence growth rates of lambs significantly. Figure 6 illustrates this in which low birth weight lambs (2.75 kg) only grew 81.25 g/day pre weaning (120 days), medium birth weight lambs (5.88 kg) grew 241 g/day and high birth weight lambs (9.50 kg) had a gain of 366 g/day pre weaning respectively. These results are in agreement with Penning et al. (1980); Villette & Theriez (1981a) who also observed significant the effects of birth weight on post-natal growth of lambs even despite artificial rearing. Furthermore in Greenwood et al.,(1998), smaller birth weight lambs had a more prolonged period of adaptation to postnatal life before weight gain was achieved and consequently grew relatively slowly for the first 2 weeks of life. This period accounted entirely for the tendency for slower growth rates overall by lambs with low birth weights (Greenwood et al., 1998). One of the reasons why low birth weight lambs are slower to grow is there is a positive association between the digestibility of feed and birth weight (Houssin & Davicco, 1979) hence growth could be limited by digestive capacity. Transition period of diet in utero to postnatal could also affect lower birth weight lambs more as they transition to a higher fat and predominantly low carbohydrate diet (Greenwood et al., 1998).

Birth weight also corresponds to the muscle mass of the individual, in this study birth weight and lean muscle (total yield) was positively correlated and this was significant. There could be limited capacity of lean tissues to utilize available nutrients which subsequently could lead to catabolism of absorbed amino acids which also could have contributed to slower growth rates of low birth weight lambs through reducing efficiency of energy utilisation (Greenwood et al., 1998). Additionally a strong relationship between weight of muscle and muscle DNA content of post-natal lambs has been demonstrated (Tullooh et al., 1986) suggesting that lambs with lower birth weights initially have fewer myonuclei from which to express transcripts for muscle protein synthesis and therefore have a limited capacity for growth of muscle compared with larger birth weight lambs (Greenwood et al., 1998).

Birth weight is moderately heritable, (19%), therefore 81% can be affected by environment (Fogarty., 1995; Safari et al., 2005). It has been observed in sheep that ewes on a low plane of nutrition during the last third of pregnancy can result in below average birth weights (Wallace, 1948). Nutrition is also a determinant of skeletal muscle development, with low birth weight lambs having less muscle DNA than larger birth weight counterparts which indicates there is less myonuclei present (Greenwood et al., 2000). The effects of under nutrition can be long term with Schinckel & Short., (1961) observing that lower birth weights due to under nutrition in late pregnancy was shown to persist up to 3 years of age and lower mature weights of offspring up to 5.5 years (Reardon & Lambourne., 1966). Later studies have also stressed the importance of nutrition during early pregnancy to meet skeletal muscle development potential which in turn would influence lean meat production in post-natal life (Zhu et al., 2006; Du et al.,2009).

Consequently in this study, birth weight significantly affected weaning weight of the lamb (table 5 and figure 7) which is of economic importance to lamb production systems as lambs that reach target weights faster and are sent off farm earlier increasing both farm productivity, efficiency and potential financial return. Another important aspect to note is birth weight also had a positive relationship with lamb final weight (WT 4) (table 7) which was highly significant so using this criteria in selecting for lambs with higher birth weights could also result in heavier final weights. However this assumption is only valid on WT 4 lambs which were sent off the farm earlier as they had reached the 36 kg target weight faster than lambs with a later drafting date (WT 5). It is also important to note that while WT 5 did have a positive relationship with birth weight it was not statistically significant. This is most likely due to a difference in sample size with more lambs being in the WT 4 category than compared with WT 5 (1503 vs 104 respectively). These results were in agreement with Han., (2012) who also found positive correlations between birth weight, tailing, weaning and growth rate in Romney sheep.

Sire also had a significant effect on lamb birth weight in this study (table 14) and this finding is well supported by other studies with Cloete et al. (1992) mentioning the significant effect of sire on lamb birth weight and also Olivier et al. (1987) found that the variance term between sire were also significant for birth weight and likewise found variation between sires for type traits. Additional to this, Kincaid (1943) informed that “the sire could influence only the hereditary characters of the lambs; it can be appeared that in certain rams within each breed transmitted characters to their lambs which influenced birth weight”. Finally Caro Petrovic et al. (2013) observed that different ram genotypes had greater birth weights and there was also variation within genotypes, for instance genotype 2 had the greatest birth weight difference of 0.42 kg between sire 1 and 2, while genotype 1 sires 1 and 2 only had a birth weight difference of 0.01 kg. Birth weight has a heritability estimate of 0.29 in the Romney breed (Blair, 1998) hence eBV values can be used to influence the sire effect on birth weight of resulting lambs successfully. For instance in this study Gatton Park 29/06 sired lambs had the lowest mean birth weight with 5.10 kg compared with Ramhill 322/11 sired lambs with the highest mean birth weight of 6.65 kg demonstrating that the sire line can influence the birth weight of the resulting progeny and this could be important to utilize for lamb production systems as this study has shown, sire selection could also influence lamb growth rates.

Selecting for an increase in birth weight alone can cause an increase in dystocia, which is a major cause of lamb death in singles over 3.6 kg (Dalton et al., 1980). However the solution to combat this issue is to select for increased litter size (fecundity) in the breeding flock. Birth weight is greatly affected by litter size, in which it has been observed that twins were 87%, triplets 75% and quads 62% of the average singleton weight (Gardner et al., 2007). Additionally to this the error term for birth weight has been found to decrease with increasing litter size which suggests that uterine spare limits variance in birth weight (Gardner et al., 2007). So selecting for increased birth weight would not be a problem if increased litter size is also selected. Strict culling decisions should be made if a ewe produces large single lambs with birthing difficulties.

5.2 Birth weight and interaction with carcass traits

Birth weight in this study has been found to have a positive correlation with lamb weaning and final weight and this result is highly significant refer to (table 7). Birth weight has also been found to influence carcass traits such as shoulder yield and total yield (lean meat production). Associations between leg and loin yield although were positive but were not significant in this study. This demonstrates that birth weight will potentially not be a good predictor of these carcass traits.

There is a limited literature and conclusive studies on the relationship between birth weight and carcass traits. However a reasonable assumption would be that due to birth weight influencing both weaning and final lamb weights lambs born heavier would reach target weights faster and have a greater carcass yield compared with smaller birth weight lambs. Lighter lambs, which would not only have slower growth rates, might not reach full potential especially in dry land farming situations when feed supply becomes limited if the production cycle is extended during summer months.

5.3 Weaning weight as a predictor of carcass traits

Weaning weight is crucial for lamb production systems as it is the first time that the potential economic value of the lambs can be predicted. Weaning weight in this study was found to be significantly positively correlated with lamb final weight (table 6 and figure 8). Hence lambs that had a higher weaning weight would most likely have a heavier final weight. This can be interpreted as the birth weight influencing weaning weight, as lambs which were born heavier, had a greater growth rate which consequently reached weaning weight faster and potentially heavier compared with lower birth weight counterparts. Furthermore lambs that were weaned heavier would reach target live weight faster and depending on feed supply could also be heavier. It was found that in Swedish sheep breeds there was a high genetic correlation between 4 month old age (weaning weight) and carcass weight (Nasholm, 2004).Therefore there is a strong indication that selection for increased live weight, yields a positively correlated response to an increase in carcass weight. Other studies have also demonstrated this close genetic relationship between live weight and carcass weights (Bennett et al., 1991; Waldon et al., 1992; Conington et al., 1998)

Weaning weight was also positively correlated with carcass traits such as loin, shoulder and total yield and this relationship was significant (table 6). Heavier lambs would have a greater total yield which would result in proportionally higher loin and shoulder yields. However there was no significant correlation between weaning weight and leg yield. Possible explanations for this are that there is a presence of a gene which is influencing the yield of leg or leg yield is not influenced by the weight of the lamb.

It was found that the sire of the lamb had a significant effect on the weaning weight of lambs. For instance Gatton Park 29/06 sired lambs had the lowest weaning weight of 30.18 kg on average compared with Ramhill 322/11 with 37.96 kg respectively (appendix B.2). This is crucial for lamb production systems as Gatton Park sired lambs would have to be retained on farm for longer to reach target weight of 36kg, while a high proportion of Ramhill sired lambs would be able to be sent straight off the ewe to the abattoir and thus create space for other stock classes on farm. Therefore the selection for rams which have a greater eBV for weaning weight could increase both farm productivity and efficiency. These results are in agreement with the heritability estimate of weaning weight in Romney sheep with 35% (Chang & Rae, 1961) therefore selecting for weaning weight could have significant animal productivity benefits. Because weaning weight is only 35% heritable, the remaining 65% of potentially high weaning rates can be affected by environment. This includes the nutrition and feed supply to the ewe which greatly influences lactation performance, (quality and quantity), feed supply to the lamb when their reliance on pasture increases as well as parasite burden. As the lamb gets older, the diet composition changes from a milk based diet to a diet with a higher proportion of pasture and this will greater increase the chance of parasite infestation which can cause a difference in growth rates up to 35% between animals on clean compared with contaminated pastures (McAnulty et al., 1982).

5.4 Final lamb weight and carcass traits/composition

In this study, the final weight of lambs had a significant positive correlation with carcass traits (loin, shoulder, lean meat and percentage of loin and shoulder yield) (table 7). Subsequently heavier lambs will have a greater carcass yield.

Genetically, correlations between lean tissue and the direct effect on the weight of the carcass are highly variable with a range between 27-53% (Pollott et al., 1994). Therefore, depending on the genotype of the individual, lean meat production and corresponding carcass weight can vary as well as carcass composition. This factor will be discussed in due course.

One of the most important significant effects that was observed in this study was the influence of sire on lamb carcass traits. For all carcass traits, the effect of sire was highly significant (table 10, 11, 12 and 13). For instance in lean meat yield, Gatton

Park 29/06 sired lambs had the lowest lean meat yield of 52.20% compared with Ramhill 322/11 sired lambs having the greatest yield of lean meat with 57.74% respectively. Lambs that were sired by Offord 414/01 had the smallest leg yield with 20.47% compared with Ramhill 322/11 sired lambs with 23.55%. For shoulder yield Snowlea 192/02 lambs had the smallest yield with 16.21% compared with Ramhill 322/11 lambs with the greatest yield of 18.41% respectively. Loin yield was also greatly affected by sire, with lambs from Doughboy 45/04 having the smallest loin yield of 13.68% compared with Ramhill 322/11 with 15.79% (Appendix B.2). The significant effects of sire on lamb carcass traits demonstrates that genetics influences carcass yield in lambs and animals can be selected for a different proportion of carcass traits for achieving more of the higher value cuts. Selection based approaches to improving the value of lamb carcasses is highly beneficial as it provides farmers the opportunity to breed individuals which have higher carcass yields, therefore are more profitable.

Furthermore carcass composition traits in sheep are moderately highly heritable (Simm, 1992) with percentage of carcass lean and fat commonly found to be 0.40 for lean and 0.45 for fat (Wolf & Smith, 1983; Simm et al., 1987). This is important because lamb production systems can change, depending on what consumers want. For instance in a Canadian customer survey in 1990 revealed that 92% of consumers that were surveyed (2002) identified excess fat as the primary reason for their refusal to purchase lamb rib chops. In the same study a low yield of meat, as reflected in the small size of chops, was the second reason for consumer rejection of lamb (5%) (Jeremiah,1990). While this was a survey conducted 27 years ago this is still crucial in understanding what the consumers prefer. Consumers demand cuts with a greater amount of useable/ consumable meat without excess fat hence why selection for larger and more muscular lambs is at the forefront of lamb production systems and corresponding breeding programs.

Rate of improvement is largely dependent on the precision of the method used to estimating body/ carcass composition *in vivo* (Stanford et al., 1998). However this goes beyond the scope of this study, but is still important to note as accuracy can greatly affect individual animal selection based indexes. It has to be accurate and reliable in order to select individuals that have beneficial traits to add into the breeding program.

Stage of maturity has a significant effect on carcass composition therefore animal based selection would also be affected. Lambs in this study were sent off farm at 36 kg live weight (final weight). Stage of maturity is crucial for a two main reasons. Firstly the age in which selection differentials for the weight of carcass fat and lean meat become established in lambs (Bennett et al., 1988). This is why it is recommended that ultrasound measurements should only be collected when lambs are over 35kg (Dodd et al., 1986) in order to select individuals with superior composition. Secondly the consumption of the fat deposition on the lamb carcass has been linked to an increase in heart disease in humans (Volk, 2007). This is due to high levels of saturated fat and cholesterol in these fat deposits. Abdominal and subcutaneous fat are considered to be unfavourable traits and are located around organs and in various depots under the skin. However intramuscular fat is seen as favourable (marbling) and in beef cattle has been associated with contributing to sensory palatability such as tenderness, juiciness and flavour (Oddy et al., 2001). This is a challenge as reducing the unfavourable fat depots will leave the meat dry with an accompanying drop in intramuscular fat levels (Yang, 2014). The growth of adipose tissues while accompanying muscle growth, beyond a certain body weight fat gain becomes large and a constant portion of weight gain (Searle et al., 1972). Therefore the stage of maturity of the lamb will affect carcass composition significantly and might not be to consumer taste or requirements.

Finally predicting carcass traits and composition with live weight alone, which this study was focused on, proved that it can be an effective tool within the Romney breed. Within breed and at the same stage of maturity live weight has been found to be able to predict carcass lean meat percentage with a residual standard deviation of 1.4 – 2.2 (Cuthbertson et al., 1984; Fortin & Shrestha, 1986). Tissues within the body follow predictable patterns of development from birth to maturity (Butterfield, 1988) however there have been exceptions such as the Texel breed having less fat and more lean tissue than expected (McCelland et al., 1976).This study has also demonstrated significant positive relationships which were highly significant between all three live weights at different stages of a lambs life cycle (birth weight, weaning weight and final weight). Therefore there is potential for carcass yield to be predicted, however this could also be influenced by other variable factors such as genotype, nutrition, disease, physical environment and age (Taylor, 1965). This study has also shown that the most significant factor in carcass traits and composition is sire selection, thus it is important that the genotype of the sire is known when assessing progeny for carcass yields and composition.

5.5 Future investigations

With the analysis from this study, some areas have been found which could be improved creating an opportunity for future research.

For birth weight 2521 male lambs were recorded, however sample sizes began to reduce after this with a considerable decrease in sample size with 1503 final lamb weights recorded. This could be the reason why the correlations between lamb final weight and birth weight although positive were very weak (0.152) but significant. Not all lambs that had recorded birth weights had final end weights recorded and this could have an impact on the strength of the correlations observed in this study. It would be worth conducting another trial which has a higher proportion of lamb final weights recorded to lamb birth weights to identify how strong the relationship between birth weight and lamb final weight is. The relationship is significant but this study cannot clarify this with precision. Only male lambs were used in this study to remove any gender effects, however ewe lambs are also processed especially from farms which don't keep replacement breeding stock. Future investigation could be to include ewe lambs and identify any gender effects in growth rate, carcass composition and traits.

This study did not include a breakdown of carcass composition in the variables measured except for lean meat production. It would have been beneficial to include composition to see if sire had a similar influence like that which was observed for lamb growth traits and carcass traits such as leg, loin and shoulder. Viascan data was only available for a few individuals and did not provide a large enough sample size to be used in this study as data used was from a 9 year period. This opens up possibilities for future research using the findings of this study to further analyse the genetic effects on growth of lambs and their carcass composition as well as specific carcass traits, This could subsequently lead to a more accurate selection based index which could identify the most beneficial genetic traits for use in lamb production systems.

Eating quality, due to lack of carcass composition data, was also not included in this study. The inclusion of this would make a good addition for future trials. Campbell et al (2011) found that there was no difference in the eating quality of low and high yielding lambs, but lambs with higher growth rates had poorer eating quality compared with lambs of lower growth rates. Therefore in future trials it would be beneficial to carry out statistical analysis of carcass composition, growth rates and corresponding eating quality to analyse if faster growing lambs are consistently associated with greater lean meat to fat ratios which can influence eating quality and might not be as attractive to high end lamb markets.

Chapter 6

Conclusion

Under an intensively managed lamb production system understanding the impact of the key growth traits of lambs is crucial in optimising both farm efficiency and productivity. The findings of this study have emphasised that birth weights are not only important for ensuring survival of lambs, but also significantly influence the growth rates of lambs pre and post weaning and the time in which target weights are reached. It has been shown that lambs that are heavier at birth grow more rapidly than low birth weight counterparts. Faster growth rates mean that optimum weaning weights are achieved quicker and consequently target finishing weights are reached faster. Lamb production systems that reach high productivity levels benefit from the effects of accelerated lamb growth rates. This enables stock to spend less time on farm which allows for a faster turnaround of stock and more efficient utilisation of feed supply for other stock classes such as breeding ewes or store lambs.

Sire was found to have a significant effect on birth weight, weaning rate and final weight. Consequently if growth rates were statistically analysed the effect would have been expected to be similar. This study also illustrates the importance of sire selection in improving lamb productivity. It was observed that some sire lines were shown to be more productive than others. Therefore ram selection is also vital in improving lamb potential. However it should be noted that sire effect is only one part of the equation, maternal effects are also important especially in terms of nutrition. Ewe lactation performance can directly impact lamb growth performance depending on the quality and quantity of ewe milk. Therefore it is not only important for ewes to be fed well during pregnancy but also during the lactation period to ensure lambs get maximum energy input from milk for growth.

Environmental influences must also be taken into account for carcass traits and composition. In order for lambs to reach full growth potential, nutrition during pregnancy is crucial for the development of skeletal muscle and in ensuring lambs reach optimal muscle number potential prior to birth as this is the only time it can be influenced and this will also significantly influence lean meat production. Nutrition during lactation, as previously discussed, is also crucial for supporting maximum growth. In summary this study has demonstrated that genetic traits play a major role in lamb production in determining potential for faster growth and desirable carcass characteristics. However these findings also re-emphasise the role of maintaining adequate nutrition in breeding ewes from the conception stage right through to weaning of their lambs to provide the potential for maximise carcass yield and subsequent quality.

Finally birth weight has not only been positively correlated with weaning and final weight of the lamb but also carcass traits, (lean meat production, loin and shoulder yield), highlighting the importance of selecting for heavier birth weights for more productive lambs. This could potentially result in higher yielding carcasses with a higher proportion of lean meat yield. However some caution should always be exercised when selecting for solely for heavy birth weights, as previously discussed in the literature review of this study, heavier birth weights have been associated with disorders such as dystocia. In practice most breeders also select for increased ovulation rate in breeding ewes which correspondingly increases litter size. Litter size decreases birth weight of lambs hence risk of dystocia would be reduced. Ewes that produce singles with associated lambing problems should be culled for two main reasons, firstly on a production basis and secondly birthing problems.
Lamb production systems therefore should be focused on not only improving birth weight of lambs, which would improve growth rates and reach target weights faster, (if nutrition is optimal) but also improving the reproduction efficiency of breeding ewes through selecting for increased fecundity.

Sheep meat exports were worth $3 billion in 2016 (MIA, 2016), being 40% of the total red meat sector which is valued at $7.5 billion and is New Zealand’s largest export earner second to dairy products (MIA, 2016). Improving lamb productivity is of major importance to the sheep industry as slower lamb growth rates has a significant impact on the efficiency of utilising feed supply. There is a significant economic benefit to the industry if affordable solutions such as selecting for birth weight could be incorporated into overall management strategies. Producing lambs which are fast growing and have leaner carcasses is of economic importance to New Zealand sheep farmers and could increase export earnings by providing New Zealand lamb producers with a competitive advantage.

Appendix A: Year and total averages for lamb growth and carcass yield traits

YEAR		BIRTH WT	TAILING WT	WEANING WT	WT 4	LEG YLD	LOIN YLD	SHLD YLD	TOTAL YIELD	%YLD LEG	%YLD LOIN	%YLD SHLD
2006	Mean	5.72	13.30	30.36	42.15	20.55	14.03	16.60	51.19	0.40	0.27	0.32
	Std. Deviation	0.93	2.82	4.88	3.20	1.11	0.78	0.90	2.29	0.01	0.01	0.01
2007	Mean	5.36	18.07	31.73	40.56	21.55	14.63	16.96	53.14	0.41	0.28	0.32
	Std. Deviation	1.06	3.94	5.54	3.58	1.18	0.86	0.90	2.56	0.01	0.01	0.01
2008	Mean	5.77		36.65	40.88	21.55	14.81	17.75	54.11	0.40	0.27	0.33
	Std. Deviation	0.97		5.56	3.27	1.23	0.98	0.91	2.72	0.01	0.01	0.01
2009	Mean	6.45	16.19	41.66		21.11	14.34	17.26	52.70	0.40	0.27	0.33
	Std. Deviation	0.93	2.53	3.49		0.99	0.82	0.75	2.21	0.01	0.01	0.01
2010	Mean	6.12	13.27	34.46	37.23	22.01	14.63	17.06	53.71	0.41	0.27	0.32
	Std. Deviation	0.80	2.42	4.67	3.42	1.33	0.89	0.84	2.69	0.01	0.01	0.01
2011	Mean	6.09	12.90	35.13	38.68	21.83	14.89	16.73	53.45	0.41	0.28	0.31
	Std. Deviation	0.77	2.70	4.29	3.57	1.22	0.86	0.95	2.64	0.01	0.01	0.01
2012	Mean	6.04	12.11	36.63	42.09	22.36	15.09	17.42	54.87	0.41	0.28	0.32
	Std. Deviation	1.05	2.53	4.95	2.98	1.05	0.76	0.86	2.20	0.01	0.01	0.01
2014	Mean			37.45	38.19	21.35	14.52	16.94	52.81			
	Std. Deviation			5.45	4.06	1.12	0.66	0.74	2.12			
2015	Mean	5.63	20.60	34.63	34.91	22.10	14.54	16.98	53.62			
	Std. Deviation	1.03	3.00	4.59	2.85	1.49	0.98	1.12	3.07			
TOTAL	Mean	5.88	14.42	35.09	40.15	21.60	14.64	17.12	53.36	0.40	0.27	0.32
	Std. Deviation	1.02	3.88	5.89	3.98	1.30	0.90	0.95	2.71	0.01	0.01	0.01

Appendix B.1: Sires with more than 30 progeny ranked from lowest to highest for birth weights

Ram ID	B WT
Gatton Park 29/06	5.10
Totaranui 367/03	5.17
Tamlet 726/02	5.25
Clifton Downs 497/04	5.26
Hermiston 67/05	5.29
Glenleith 28/05	5.32
Merrydown 894/05	5.34
Longridge 626/02	5.47
Fernvale 671/06	5.48
Fernvale 1106/02	5.51
Doughboy 41/06	5.55
Gatton Park 6/06	5.56
Mana 90/01	5.59
Hermiston 100/06	5.60
Armidale 208/05	5.64
Armidale 166/06	5.65
Offord 414/01	5.68
Gleneyre 10/10	5.70
Suddley 181/06	5.70
Doughboy 67/07	5.70
Glenleith 25/02	5.73
Hermiston 22/04	5.80
Ramhill 1264/03	5.81
Doughboy 203/09	5.87
Doughboy 45/04	5.90
Gleneyre 127/11	5.92
Gleneyre 5/10	5.92
Gleneyre 192/10	5.99
Snowlea 192/02	6.01
Gleneyre 168/11	6.01
Totaranui 1572/05	6.02
Doughboy 19/10	6.06
Gleneyre 8/11	6.17
Doughboy 3/09	6.19
Gatton Park 6/06	6.21
Glenleith 248/07	6.37
Doughboy 52/10	6.41
Glenleith 210/11	6.45
Gatton Park 210/09	6.49
Ramhill 322/11	6.65

Appendix B.2: sires with more than 30 progeny and mean values on weaning, lamb final weight and carcass yield traits

Ram	*Weaning Wt*	*Wt 4*	*LEG YLD*	*LOIN YLD*	*SHLD YLD*	*TOTAL YIELD*	*%YLD LEG*	*%YLD LOIN*	*%YLD SHLD*
Gatton Park 29/06	30.18	39.53	21.10	14.33	16.67	52.10	0.40	0.28	0.32
Totaranui 367/03	30.86	40.15	21.36	14.68	16.70	52.74	0.41	0.28	0.32
Tamlet 726/02	32.36	40.67	21.28	14.37	17.09	52.75	0.40	0.27	0.32
Clifton Downs 497/04	31.86	40.95	21.74	14.62	16.98	53.33	0.41	0.27	0.32
Hermiston 67/05	32.13	39.42	21.50	14.50	16.68	52.68	0.41	0.28	0.32
Glenleith 28/05	32.12	41.57	21.47	14.61	17.05	53.14	0.40	0.27	0.32
Merrydown 894/05	31.97	40.59	22.19	14.96	17.69	54.83	0.40	0.27	0.32
Longridge 626/02	29.47	42.90	20.62	14.06	16.28	50.96	0.40	0.28	0.32
Fernvale 671/06	35.27	41.69	21.46	15.13	18.04	54.64	0.39	0.28	0.33
Fernvale 1106/02	31.34	41.97	21.67	14.74	16.94	53.35	0.41	0.28	0.32
Doughboy 41/06	34.57	39.57	21.84	14.92	17.45	54.21	0.40	0.28	0.32
Gatton Park 6/06	36.79	37.10	21.40	14.48	16.82	52.71	0.41	0.27	0.32
Mana 90/01	30.83	42.14	20.64	14.00	16.76	51.40	0.40	0.27	0.33
Hermiston 100/06	35.81	40.44	21.28	14.37	17.54	53.19	0.40	0.27	0.33
Armidale 208/05	31.55	41.15	21.58	14.76	17.04	53.38	0.40	0.28	0.32
Armidale 166/06	37.63	42.41	21.17	14.70	17.56	53.43	0.40	0.28	0.33
Offord 414/01	29.94	42.78	20.47	14.09	16.73	51.30	0.40	0.27	0.33
Gleneyre 10/10	38.20	41.82	22.48	15.18	17.66	55.32	0.41	0.27	0.32
Suddley 181/06	33.58	41.05	21.25	14.58	16.64	52.47	0.41	0.28	0.32
Doughboy 67/07	34.42	38.30	22.18	14.88	17.70	54.76	0.41	0.27	0.32
Glenleith 25/02	30.43	42.73	20.29	13.99	16.28	50.56	0.40	0.28	0.32
Hermiston 22/04	28.37	41.45	21.20	14.28	16.78	52.27	0.41	0.27	0.32
Ramhill 1264/03	35.02	40.73	21.86	14.68	16.87	53.41	0.41	0.27	0.32
Doughboy 203/09	36.95	42.31	22.55	15.27	17.55	55.37	0.41	0.28	0.32
Doughboy 45/04	30.11	42.64	20.29	13.68	16.49	50.46	0.40	0.27	0.33
Gleneyre 127/11	36.29	42.66	22.45	15.15	17.74	55.34	0.41	0.27	0.32
Gleneyre 5/10	34.17	37.07	21.87	14.98	16.76	53.61	0.41	0.28	0.31
Gleneyre 192/10	36.07	39.63	21.97	15.14	16.92	54.03	0.41	0.28	0.31
Snowlea 192/02	31.03	42.00	20.56	13.93	16.21	50.70	0.41	0.27	0.32
Gleneyre 168/11	37.85	43.92	22.33	15.05	17.24	54.62	0.41	0.28	0.32
Totaranui 1572/05	34.05	37.13	22.36	14.73	17.11	54.20	0.41	0.27	0.32
Doughboy 19/10	36.96	42.20	22.74	15.09	17.77	55.60	0.41	0.27	0.32
Gleneyre 8/11	36.59	42.26	22.34	15.07	17.62	55.03	0.41	0.27	0.32
Doughboy 3/09	35.26	37.82	21.67	14.39	17.06	53.12	0.41	0.27	0.32
Gatton Park 6/06	36.79	37.10	21.40	14.48	16.82	52.71	0.41	0.27	0.32
Glenleith 248/07	36.47	37.03	21.93	14.71	17.12	53.76	0.41	0.27	0.32
Doughboy 52/10	35.51	40.04	21.46	14.57	16.55	52.58	0.41	0.28	0.31
Glenleith 210/11	37.39	43.58	22.32	15.30	17.41	55.03	0.41	0.28	0.32
Gatton Park 210/09	37.40	42.96	22.36	15.20	17.17	54.74	0.41	0.28	0.31
Ramhill 322/11	37.96	42.47	23.55	15.79	18.41	57.74	0.41	0.27	0.32

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